

# RESIDENTIAL & COMMERCIAL WOOD-BURNING CONTRIBUTIONS TO WINTERTIME PM<sub>2.5</sub> IN UTAH

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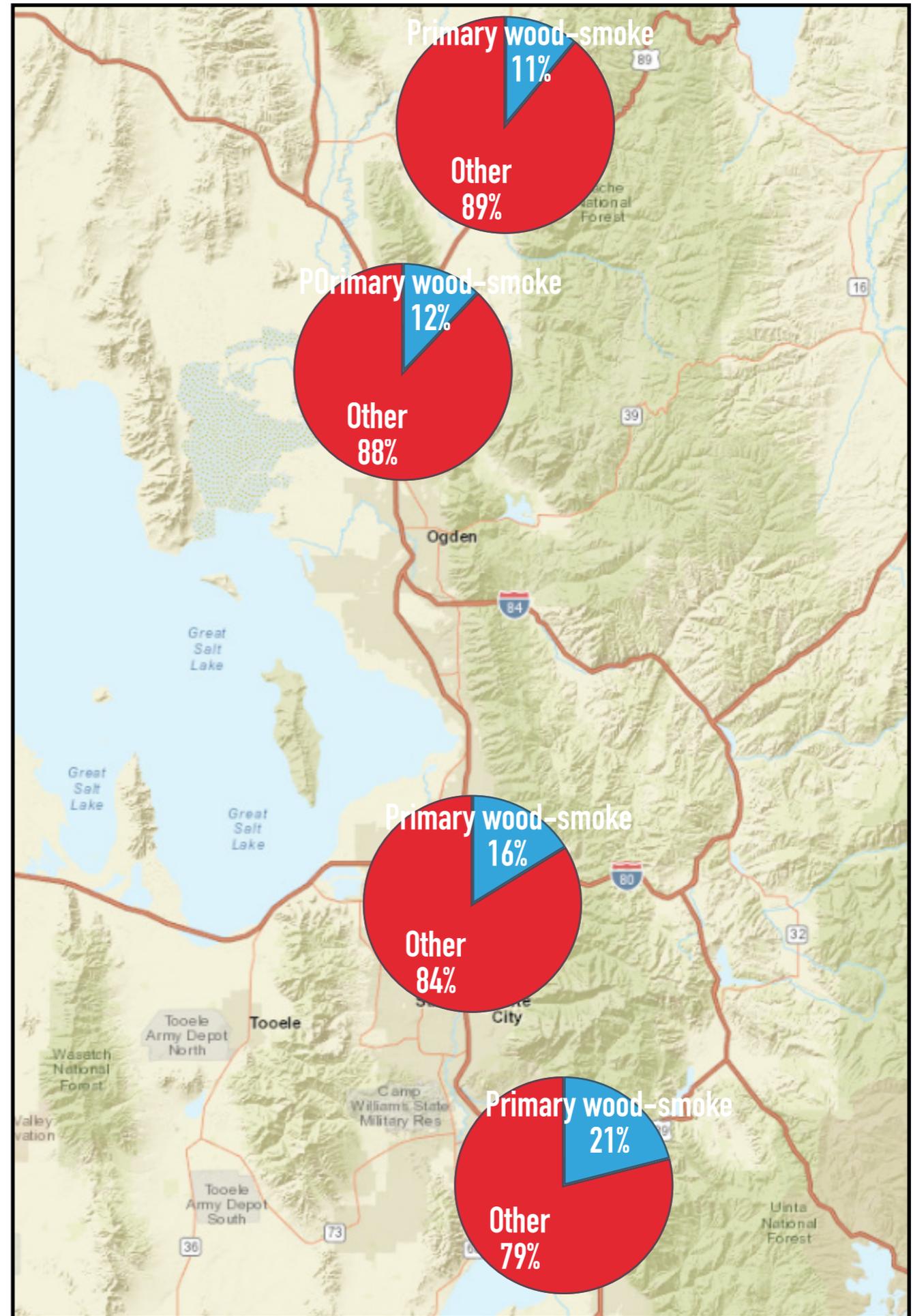
<sup>1</sup>UNIVERSITY OF UTAH

<sup>2</sup>UTAH DIVISION OF AIR QUALITY



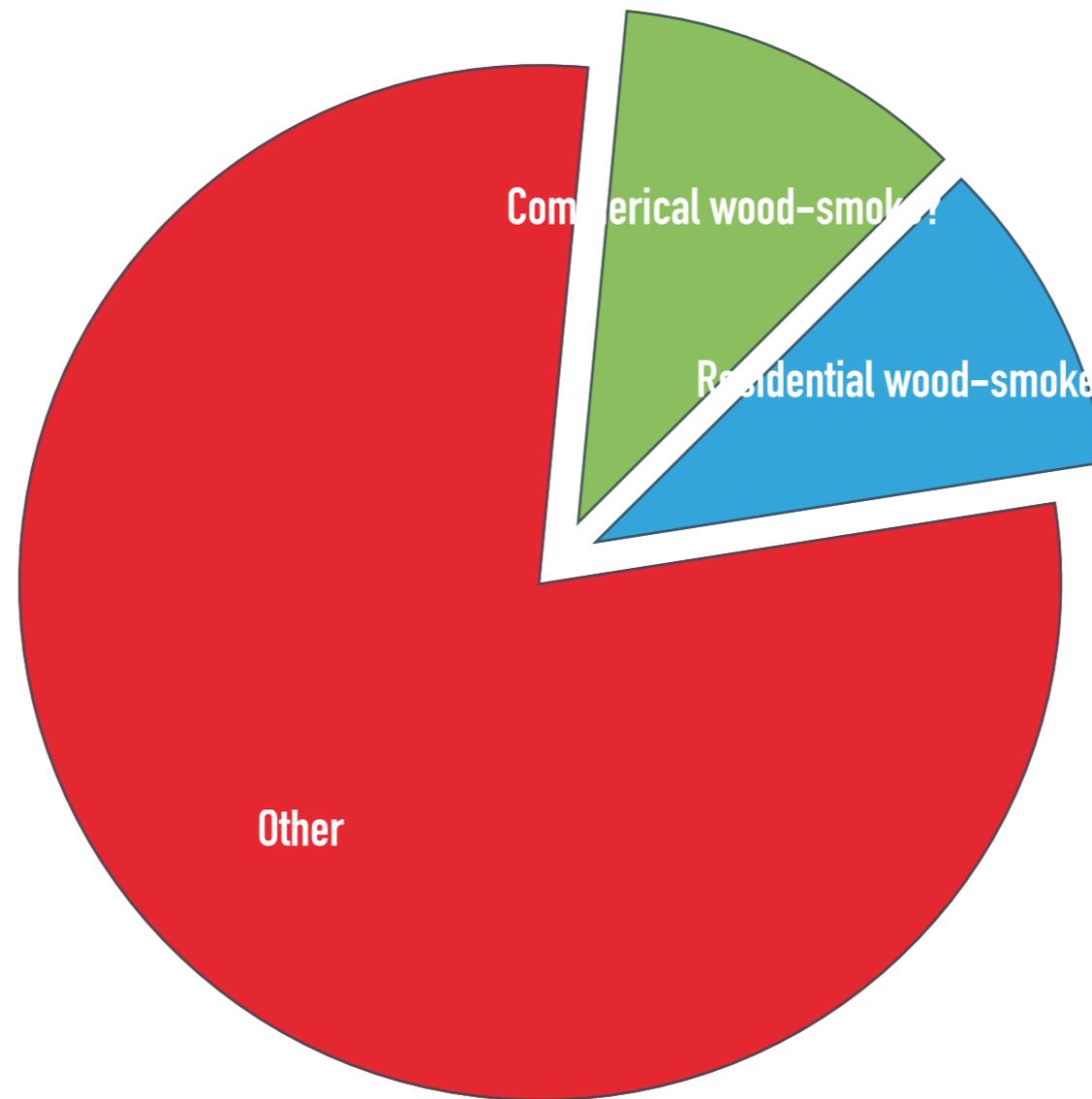
AIR QUALITY

# WOOD-BURNING AN IMPORTANT CONTRIBUTOR TO WINTER-TIME PM2.5



# OBJECTIVE

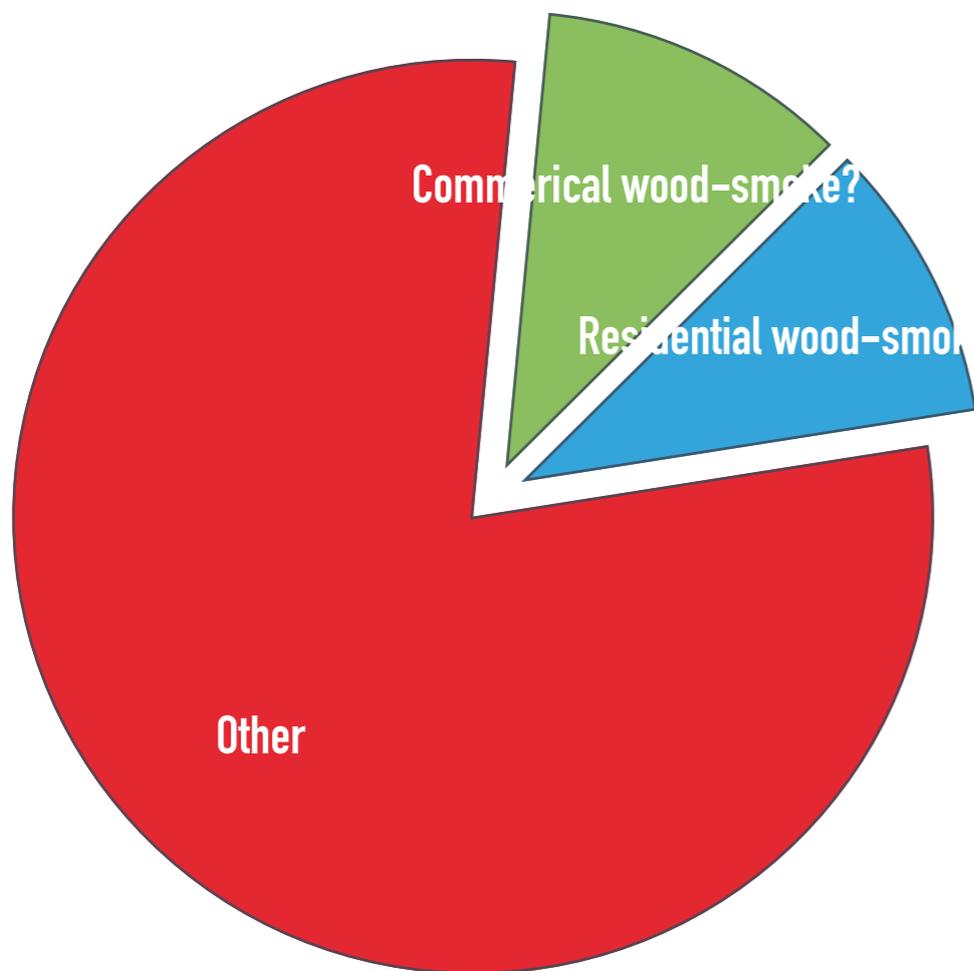
## PM2.5 SOURCES



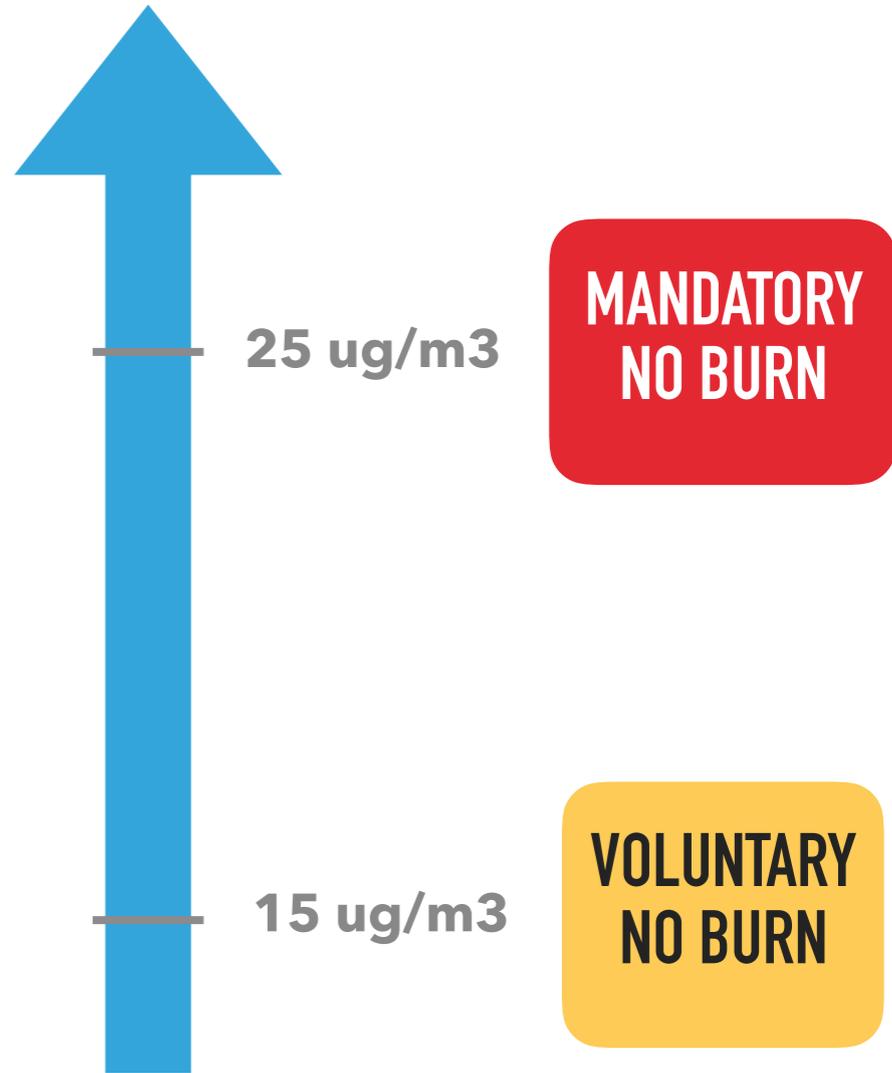
**RESIDENTIAL VS. COMMERCIAL WOOD-BURNING CONTRIBUTION TO PM2.5?**

# OBJECTIVE

## PM2.5 SOURCES



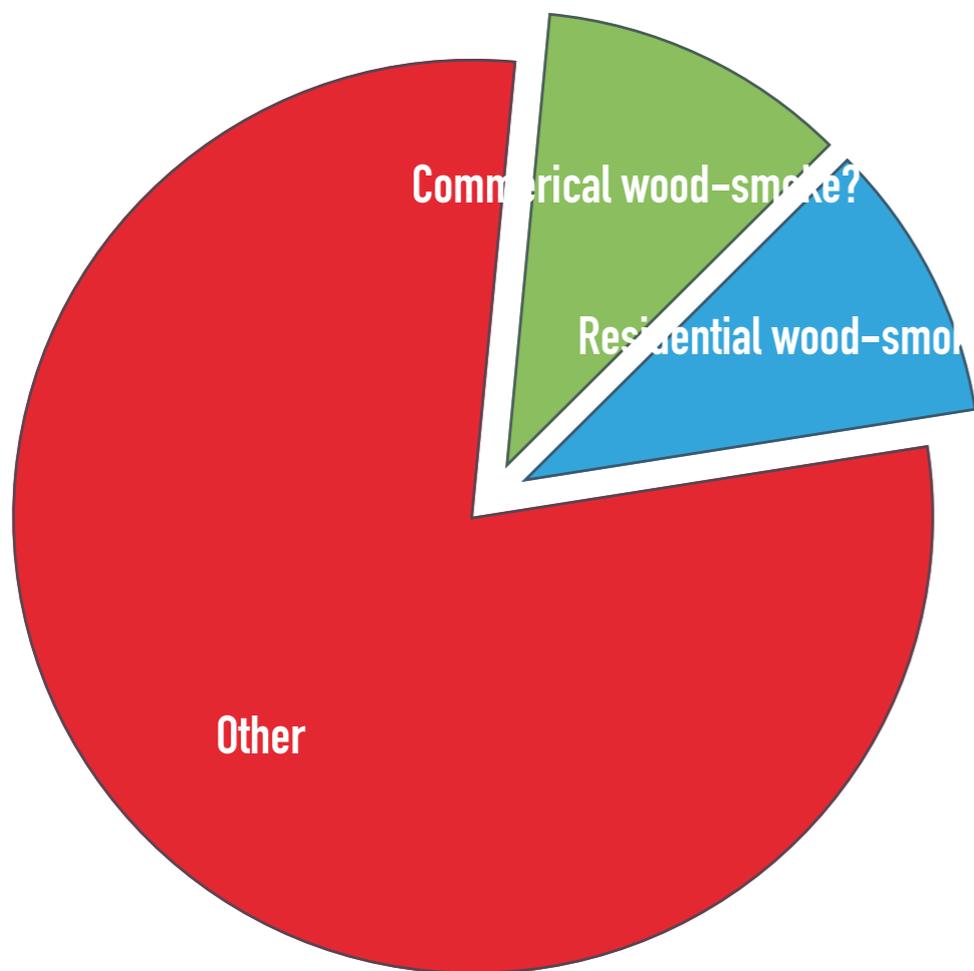
## CURRENT REGULATIONS



**RESIDENTIAL VS. COMMERCIAL WOOD-BURNING CONTRIBUTION TO PM2.5?**

# OBJECTIVE

## PM2.5 SOURCES



## CURRENT REGULATIONS

**RESTAURANTS & INSTITUTIONAL  
FOOD PREPARATION FACILITIES  
EXEMPT  
FROM NO-BURN RESTRICTIONS**

# METHODOLOGY

STATIONARY  
MEASUREMENTS



MOBILE  
MEASUREMENTS

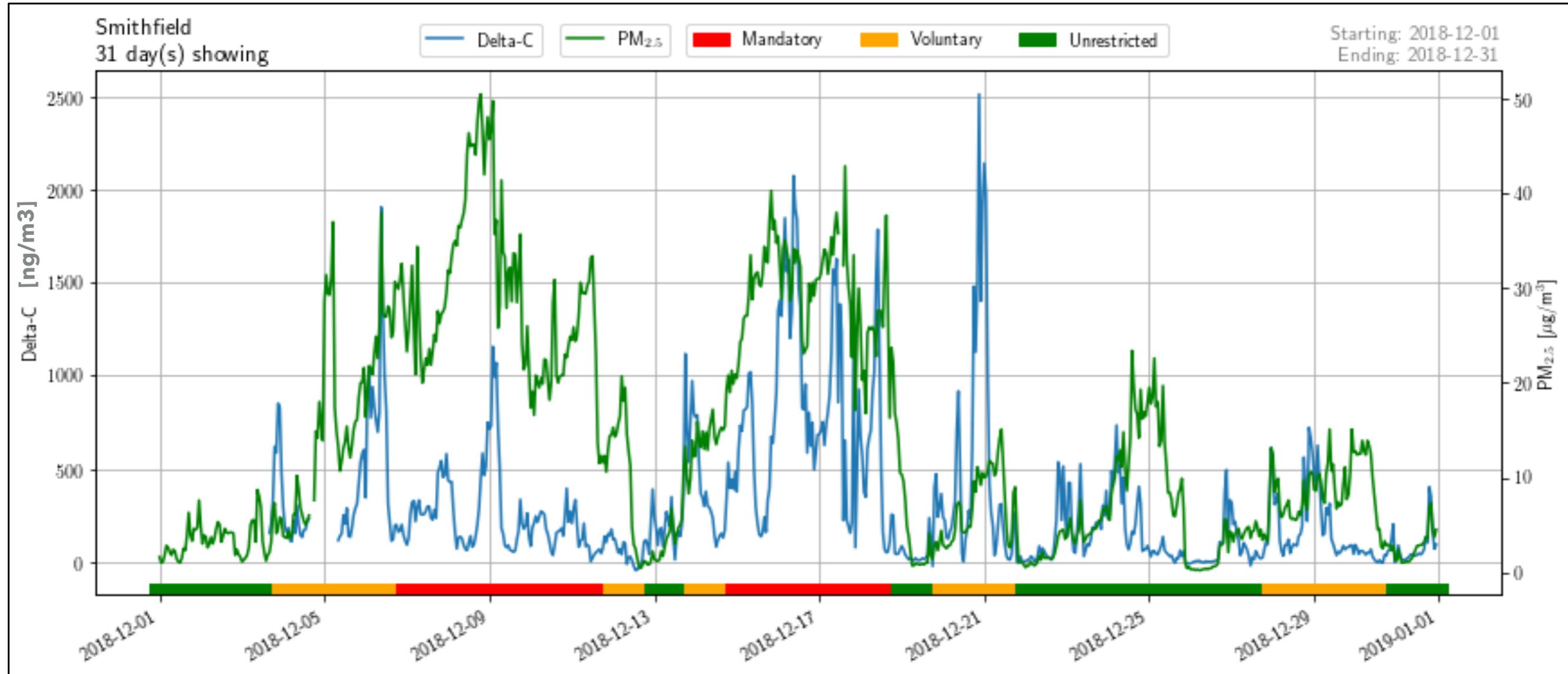


- ▶ 7-wavelength aethalometer (AE33)
- ▶  $\Delta C = UVBC(370 \text{ nm}) - BC(880 \text{ nm})$
- ▶ Indicator of wood-burning

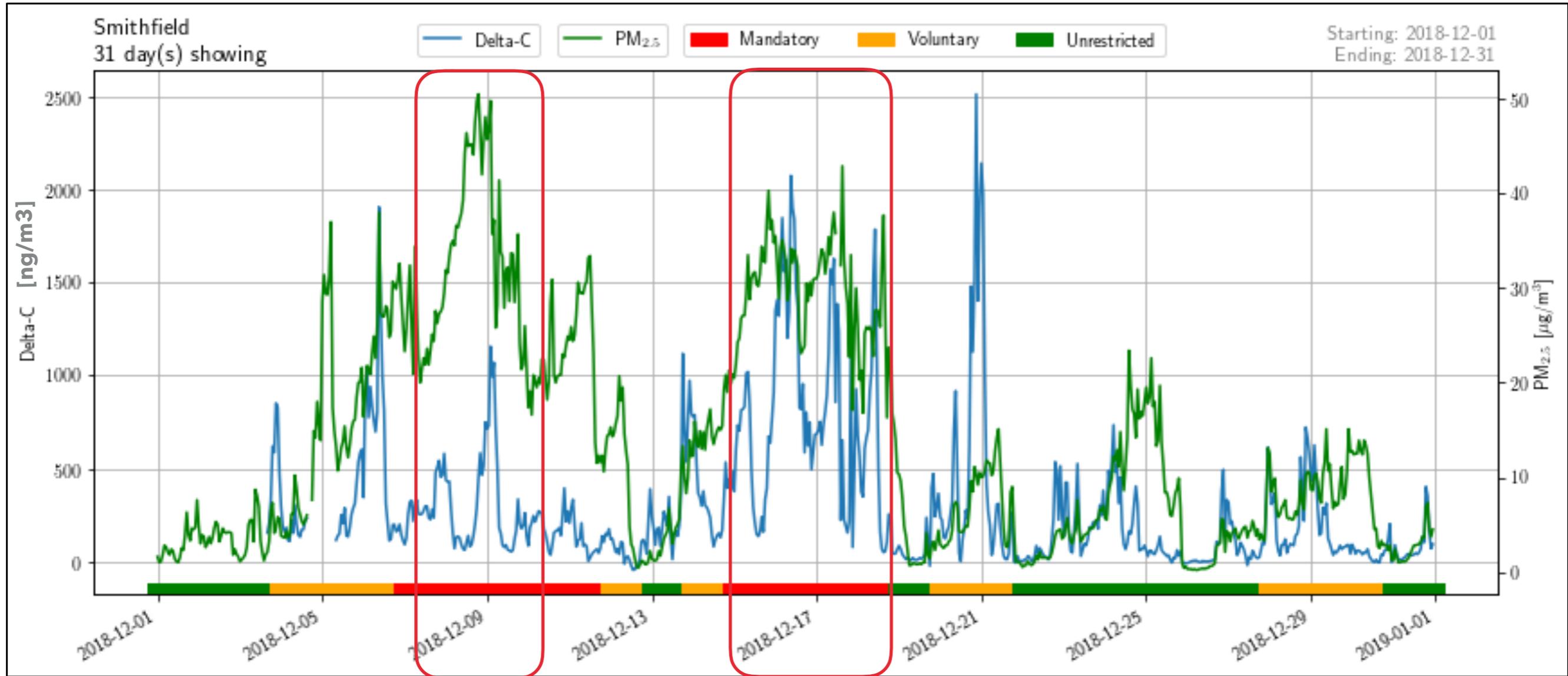
# STATIONARY MONITORING



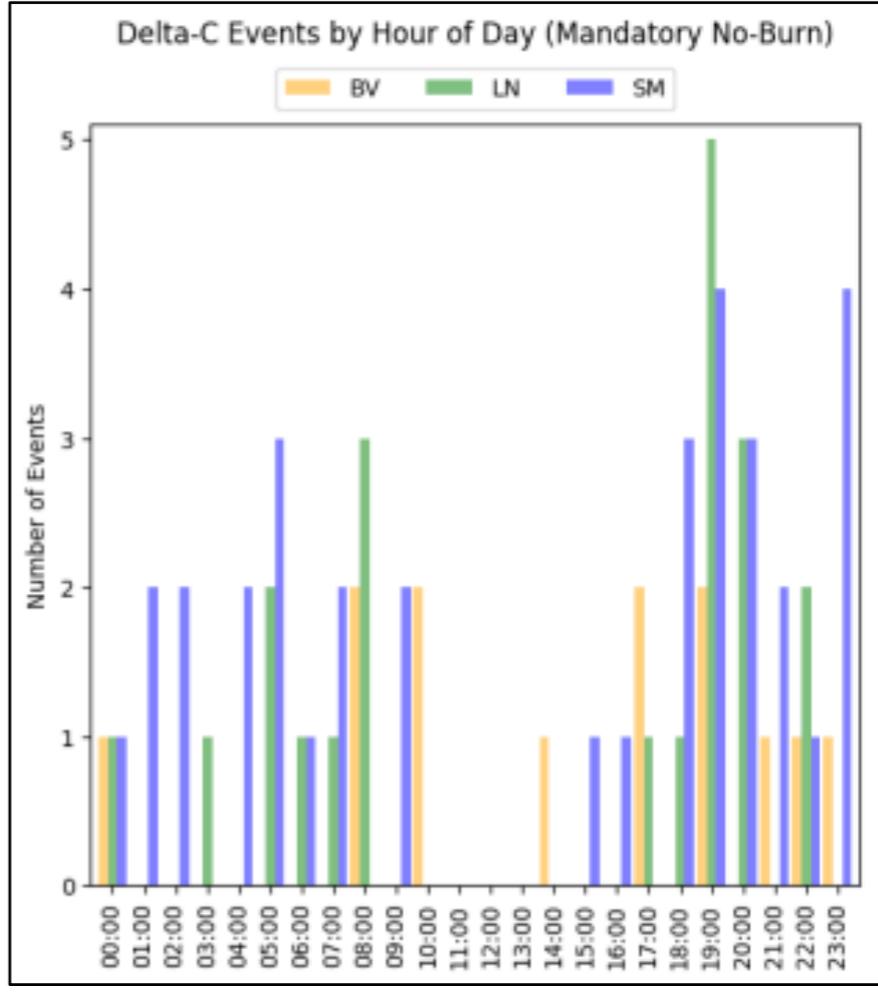
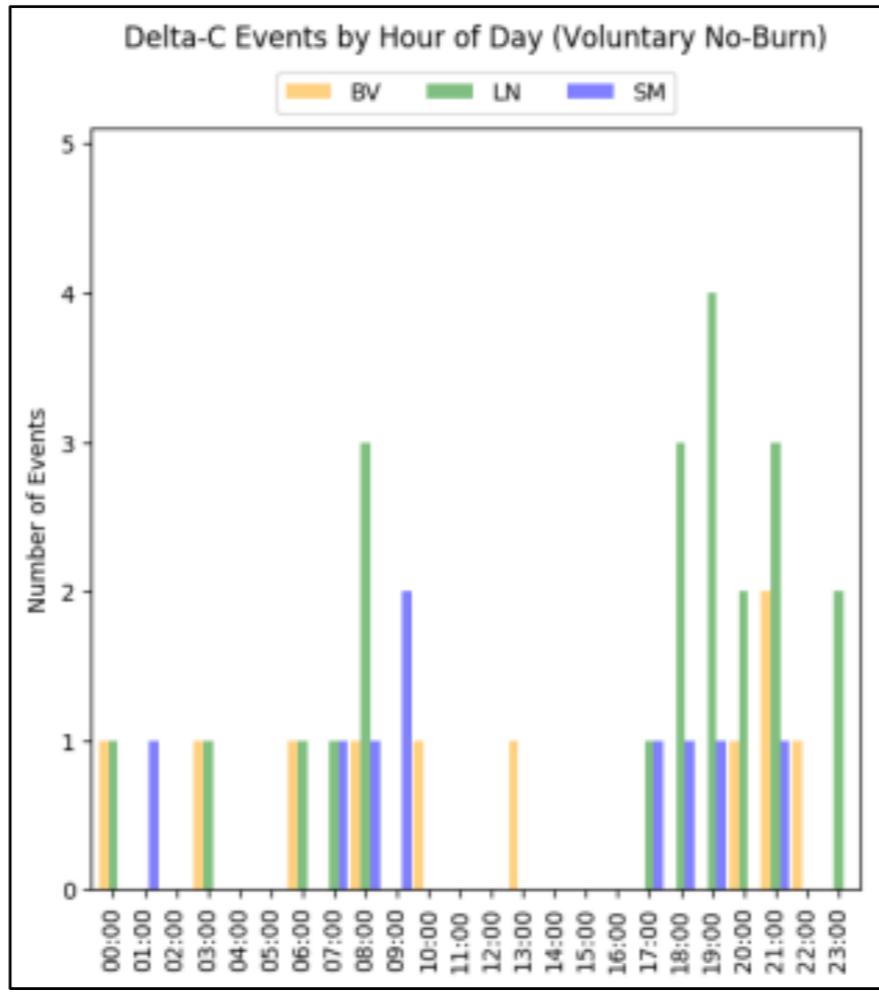
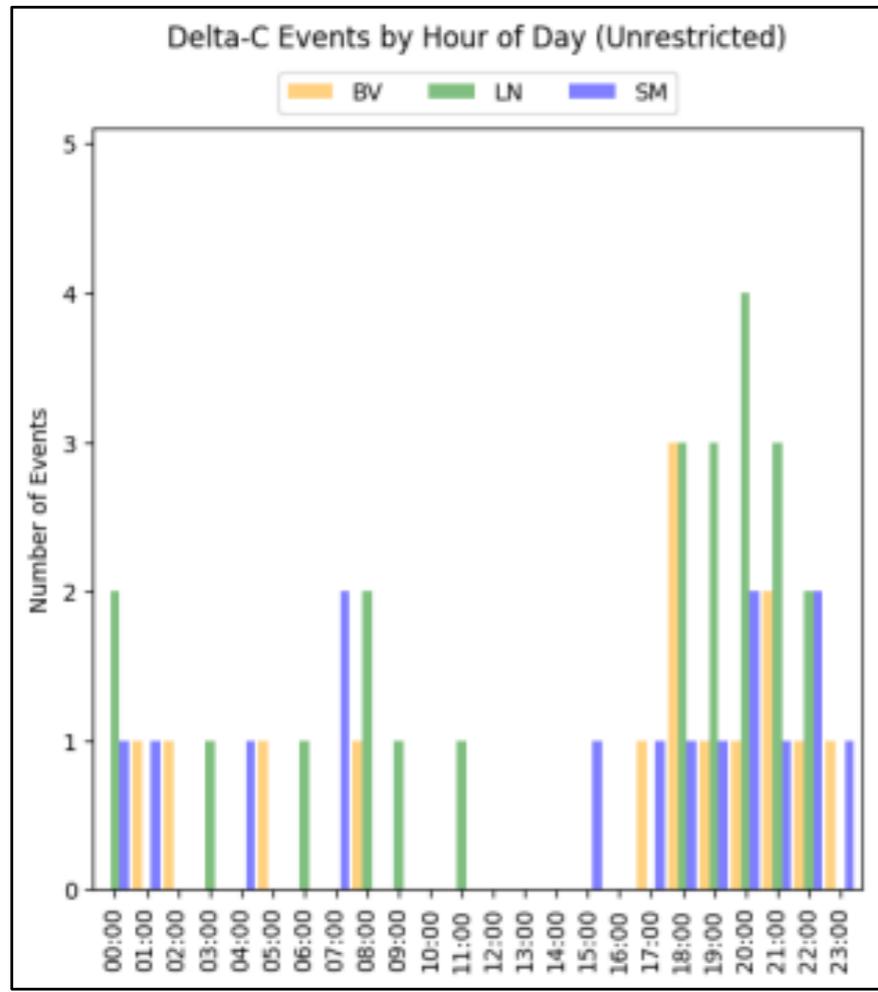
# DELTA-C & PM2.5



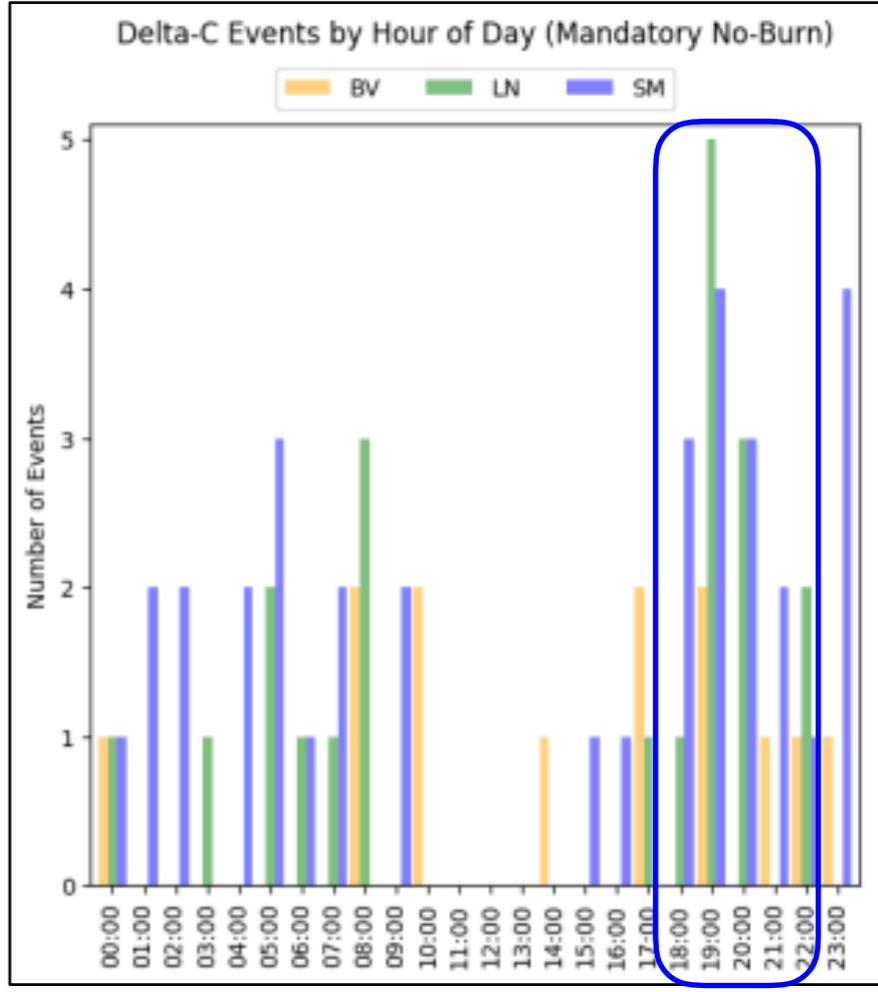
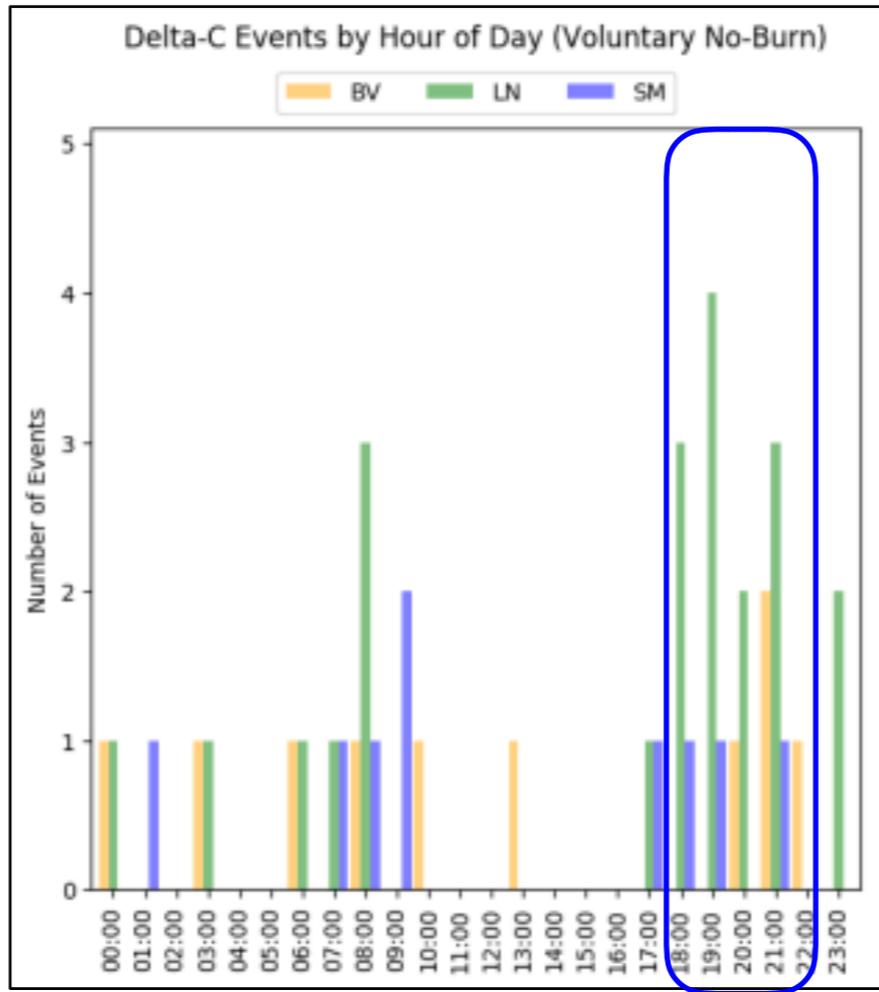
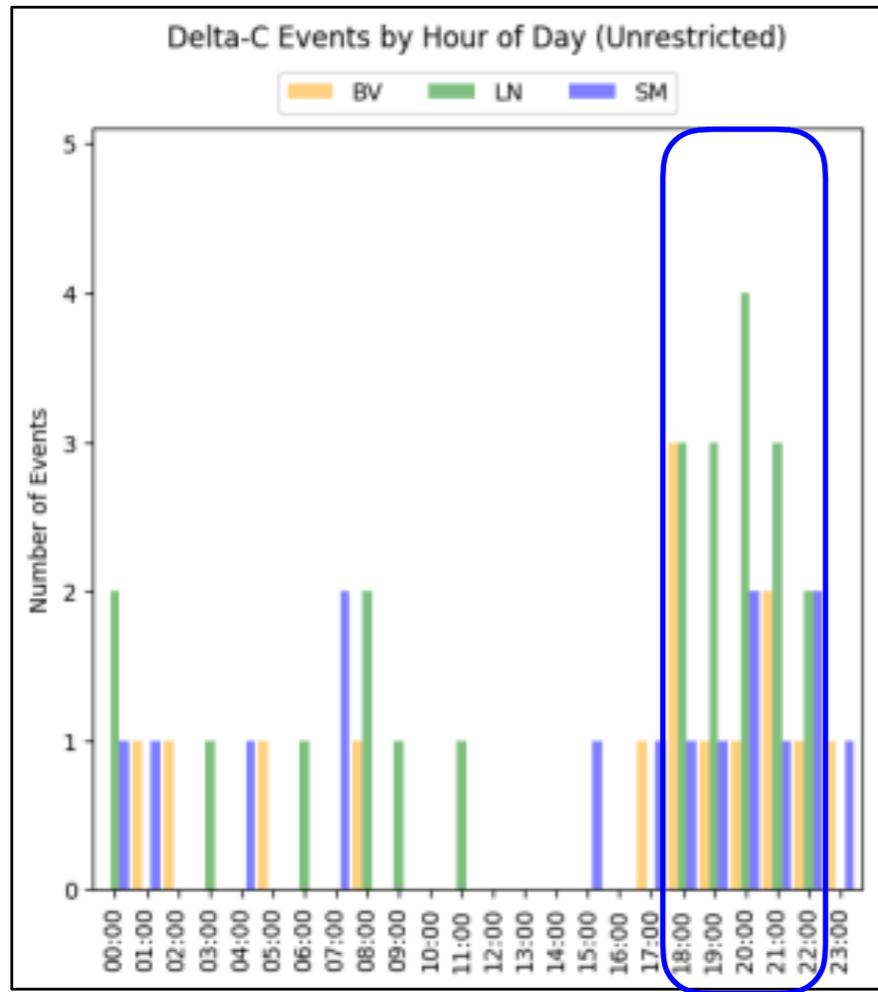
# DELTA-C & PM2.5



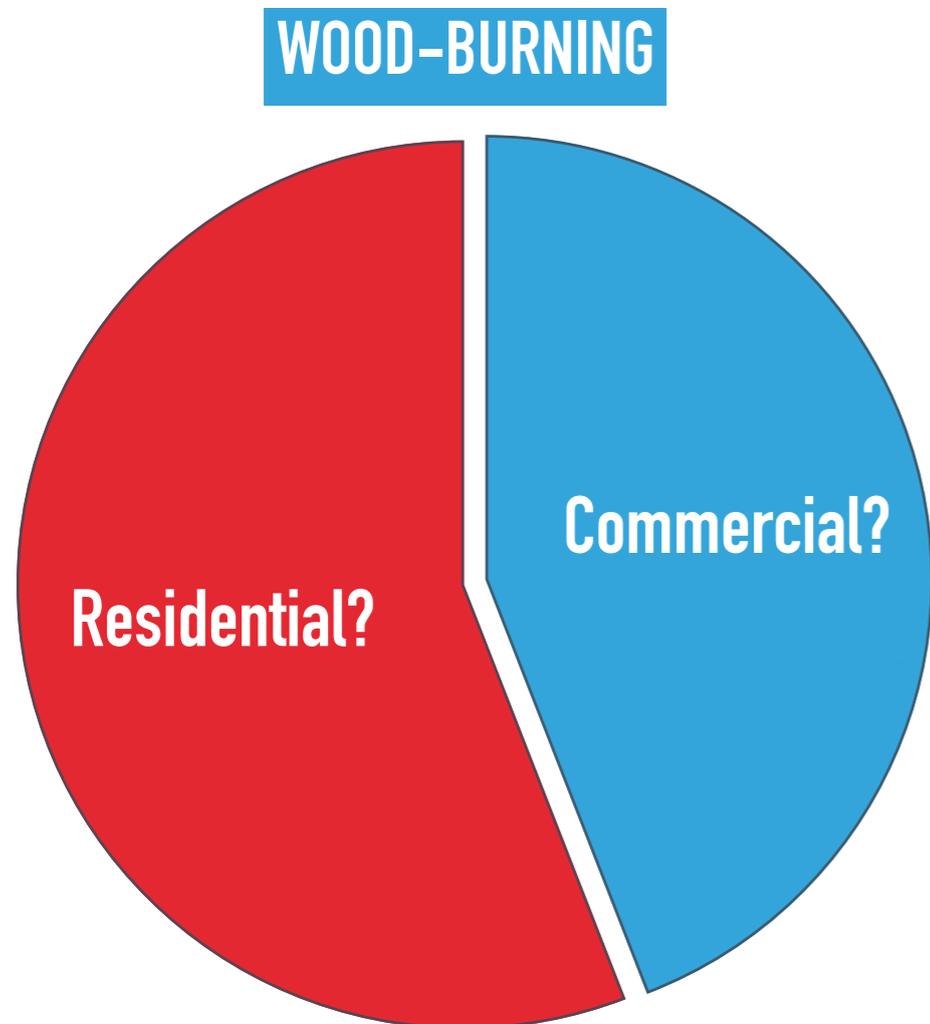
# WOOD-BURNING EVENT OCCURRENCE PER TIME OF DAY



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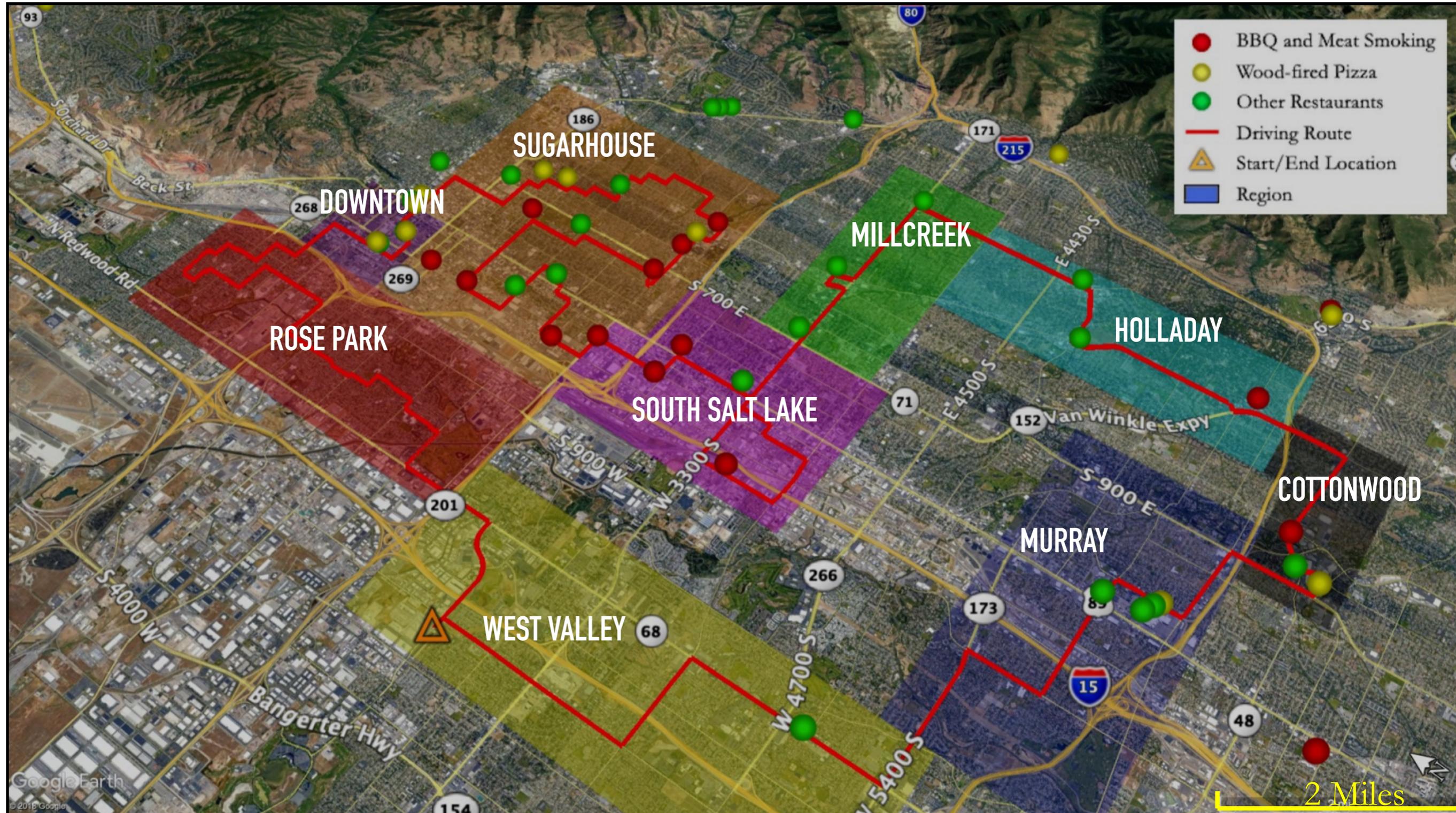
# MOBILE MONITORING: METHODOLOGY



- ▶ Aethalometer (Delta -C)
- ▶ DustTrak (PM<sub>2.5</sub>)
- ▶ GPS (Location)
  
- ▶ Sampling at 1-sec interval
- ▶ Jan. 16 - Feb.12 2019
- ▶ Between 6-10 pm
- ▶ 3.5 hrs



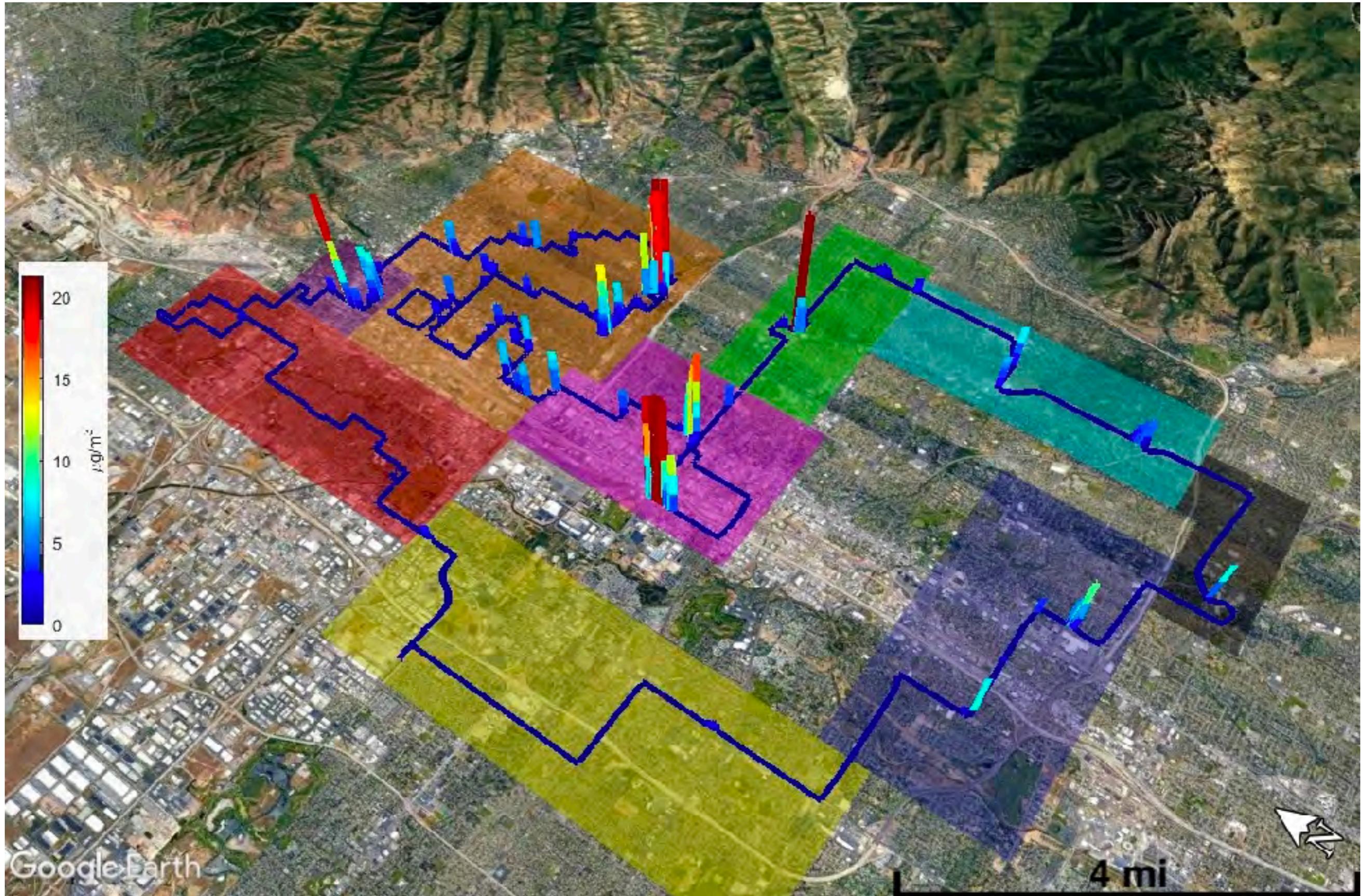
# MOBILE MONITORING ROUTE



# HOW TO IDENTIFY A WOOD-BURNING EVENT?

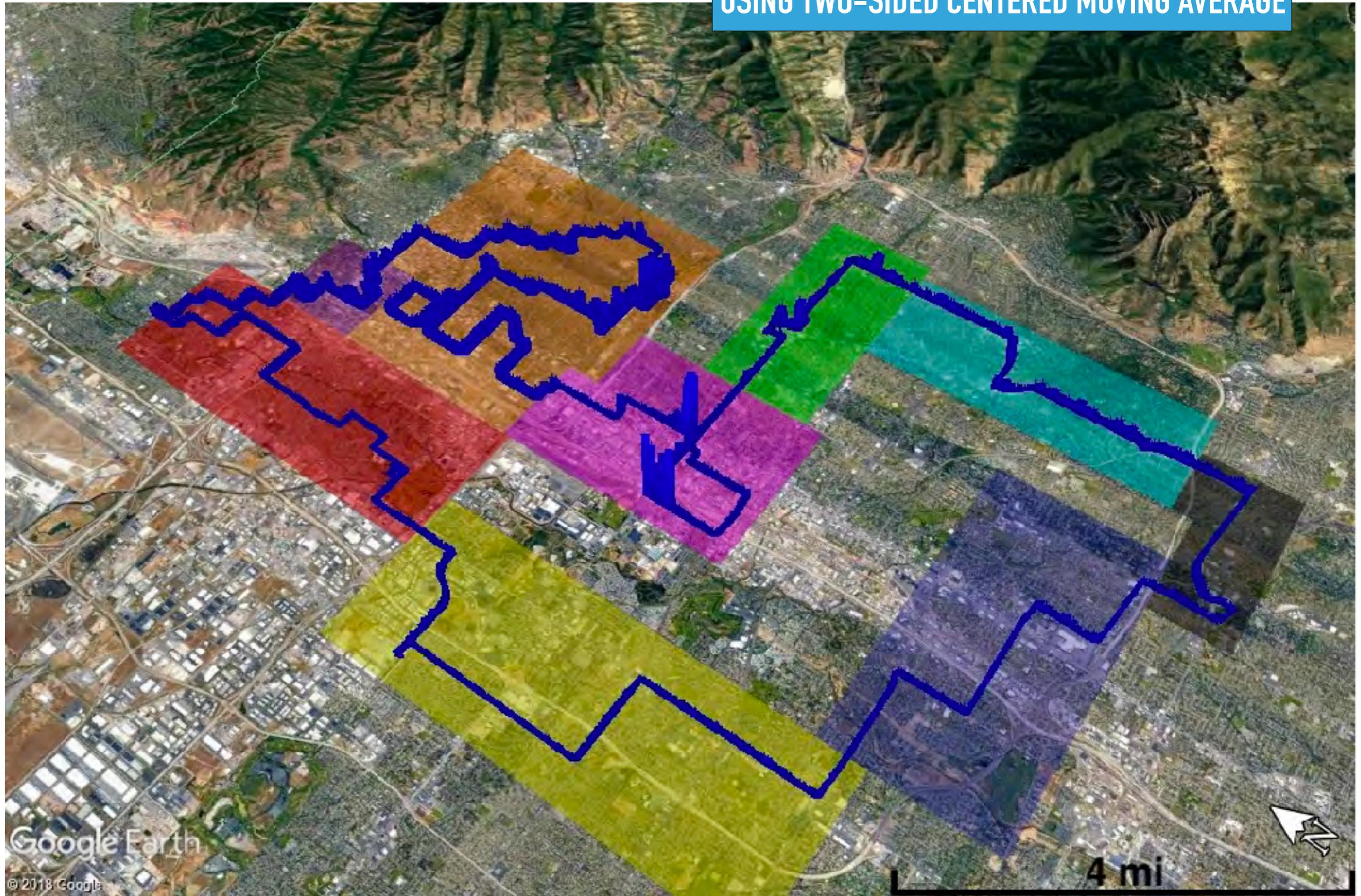


# BASELINE ESTIMATION



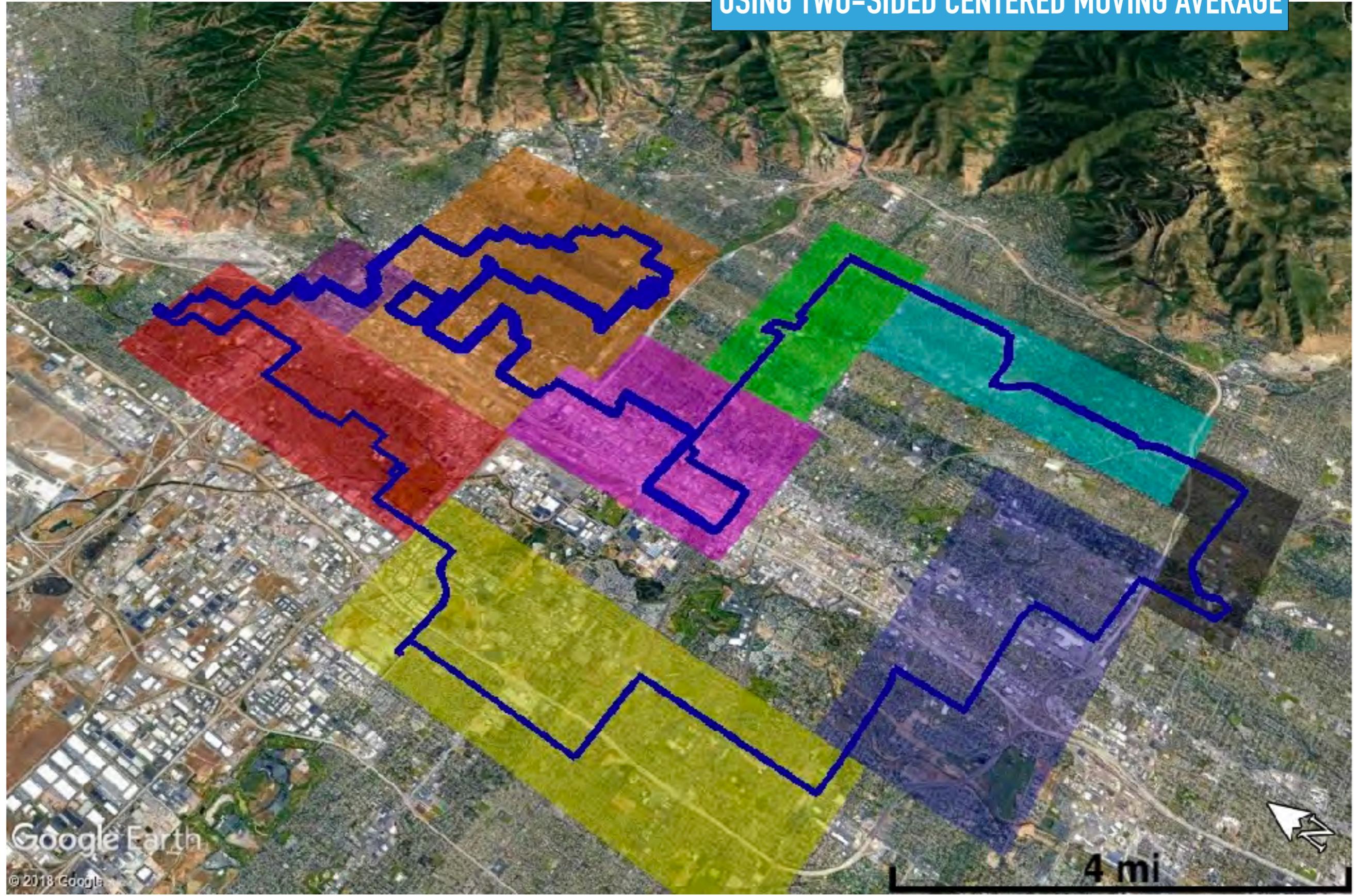
# BASELINE ESTIMATION

SMOOTHING  
USING TWO-SIDED CENTERED MOVING AVERAGE

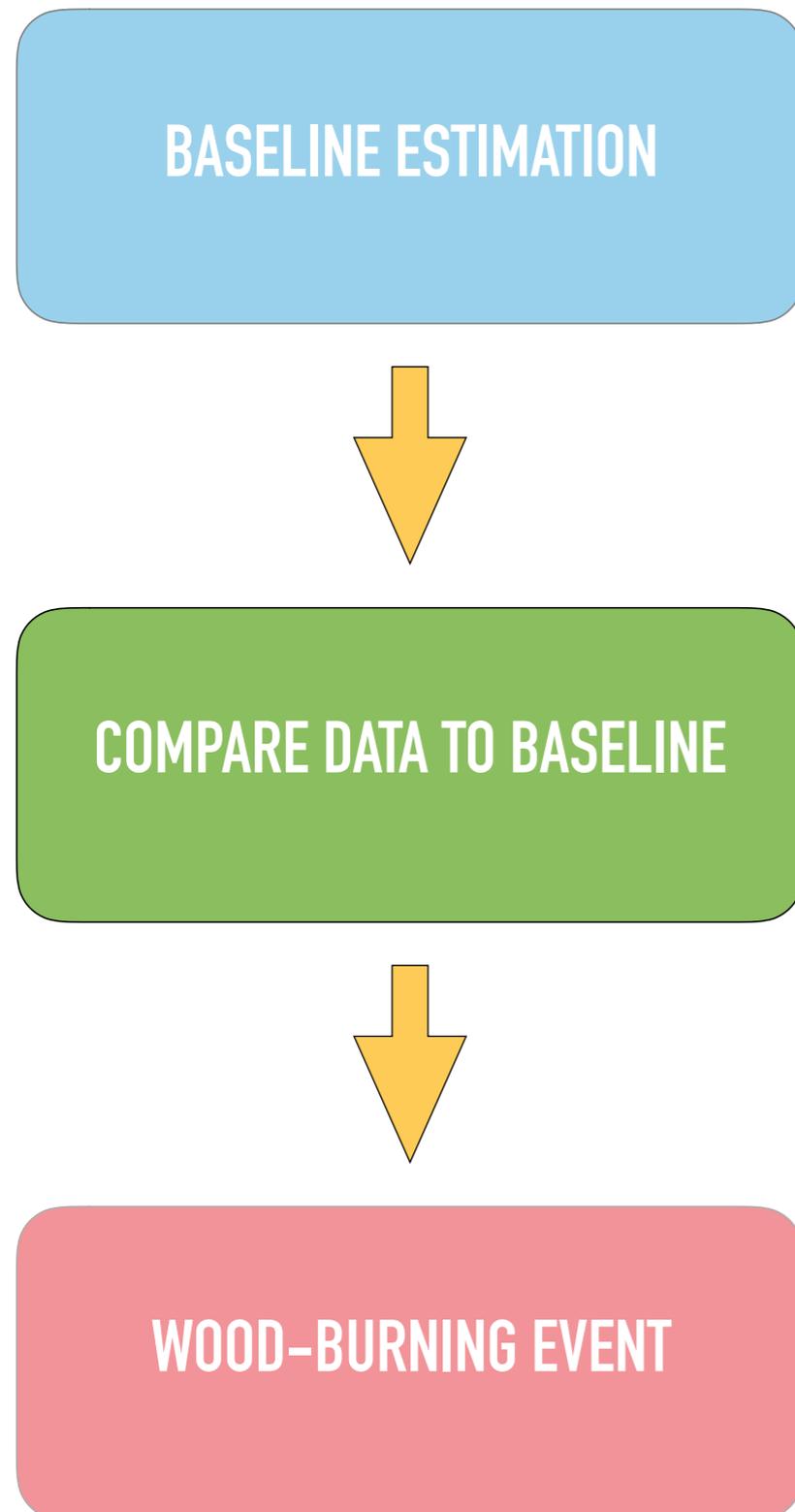


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# HOW TO IDENTIFY A WOOD-BURNING EVENT?



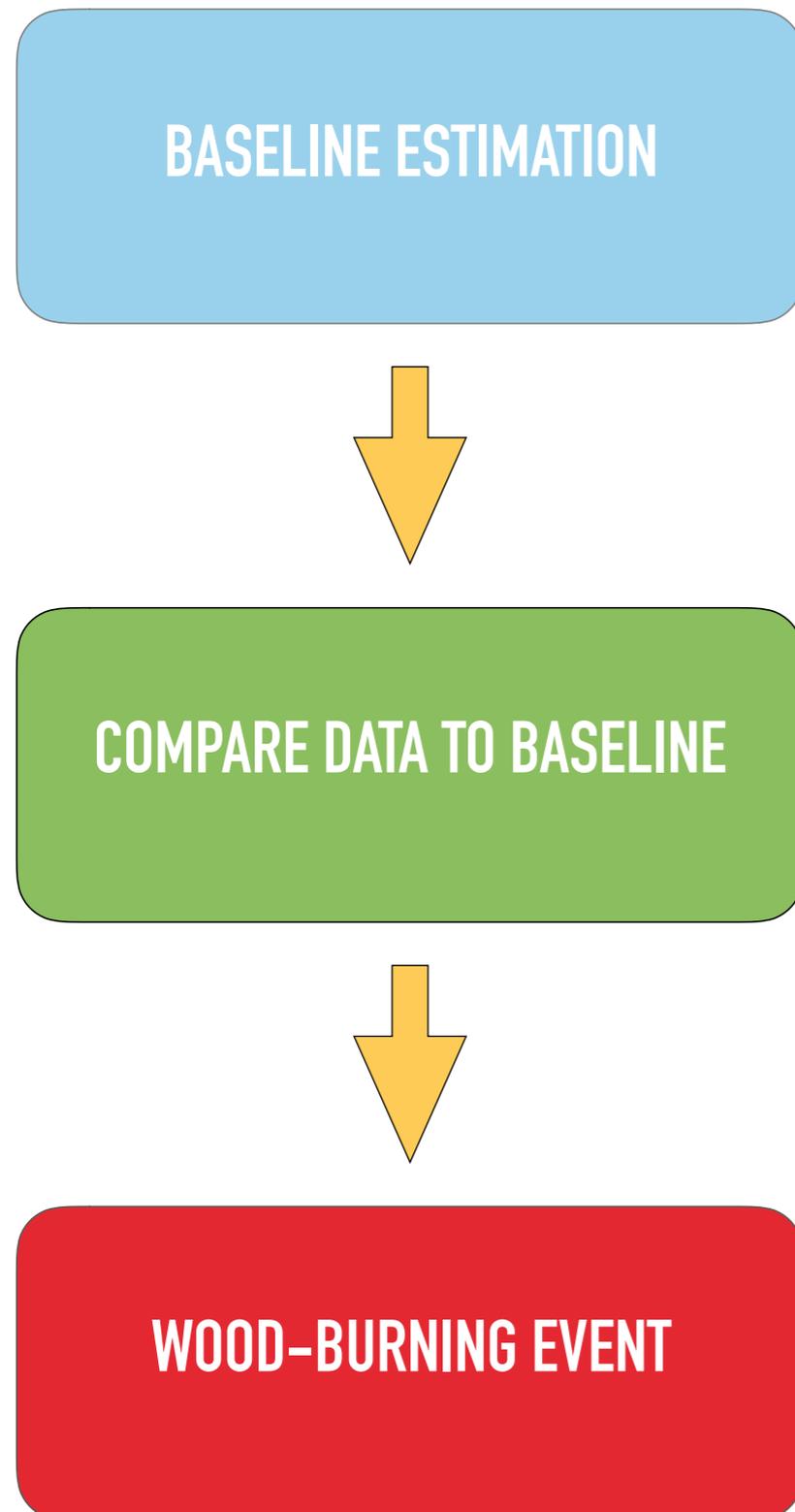
$$\text{Event if } \left\{ \begin{array}{l} x_{t+\delta}^{PM} - \beta_{t+\delta}^{PM} \geq 2.5 \times \sum_{t+} \sigma_{t+\delta}^{PM} \\ x_{t+\delta}^{Delta-C} - \beta_{t+\delta}^{Delta-C} \geq 2.5 \times \sum_{t+} \sigma_{t+\delta}^{Delta-C} \end{array} \right\}$$

$x$  is PM2.5 or delta-C value

$\beta$  is baseline value

$\sigma$  is centered moving standard deviation

# HOW TO IDENTIFY A WOOD-BURNING EVENT?



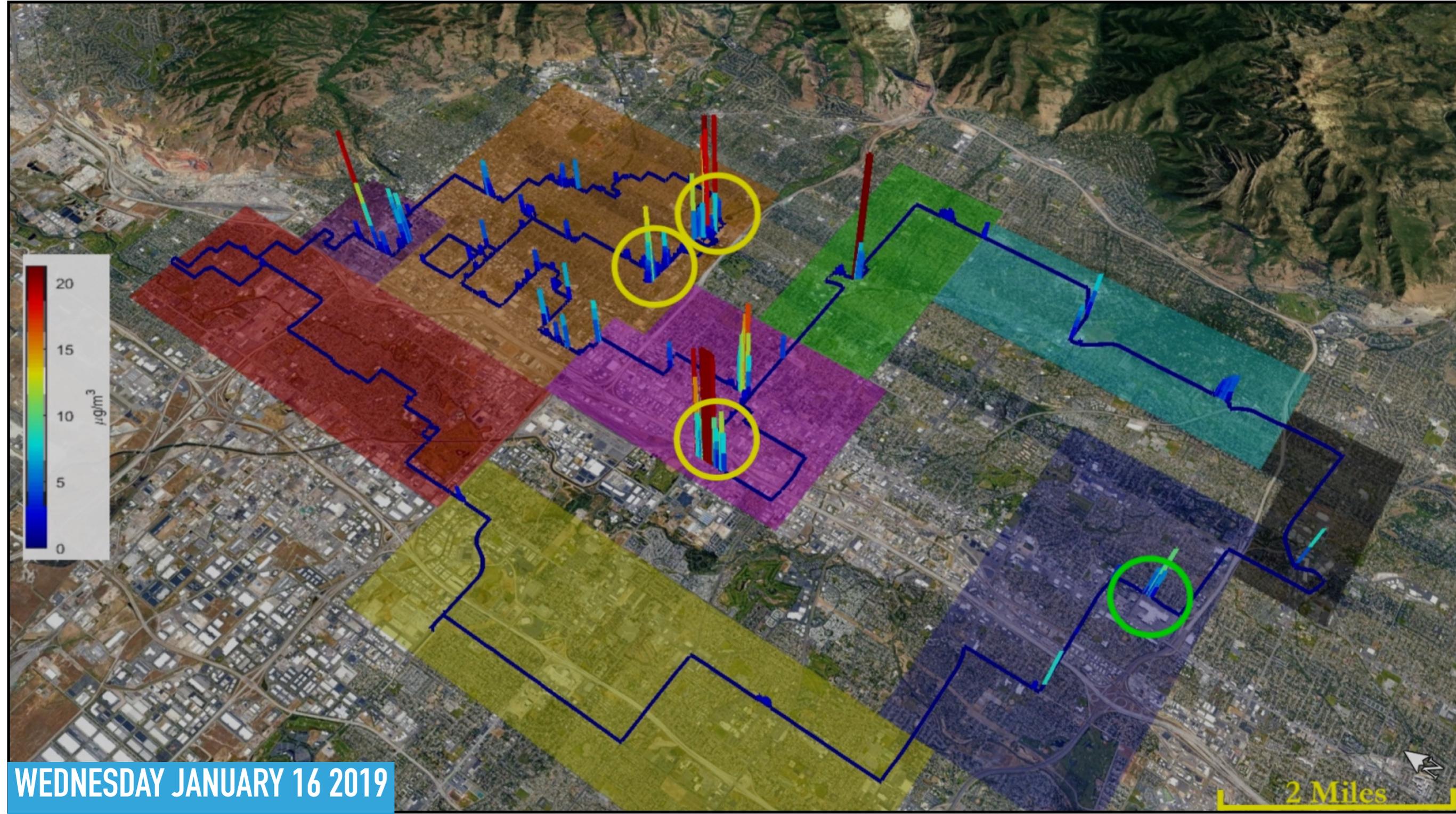
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$x$  is PM2.5 or delta-C value

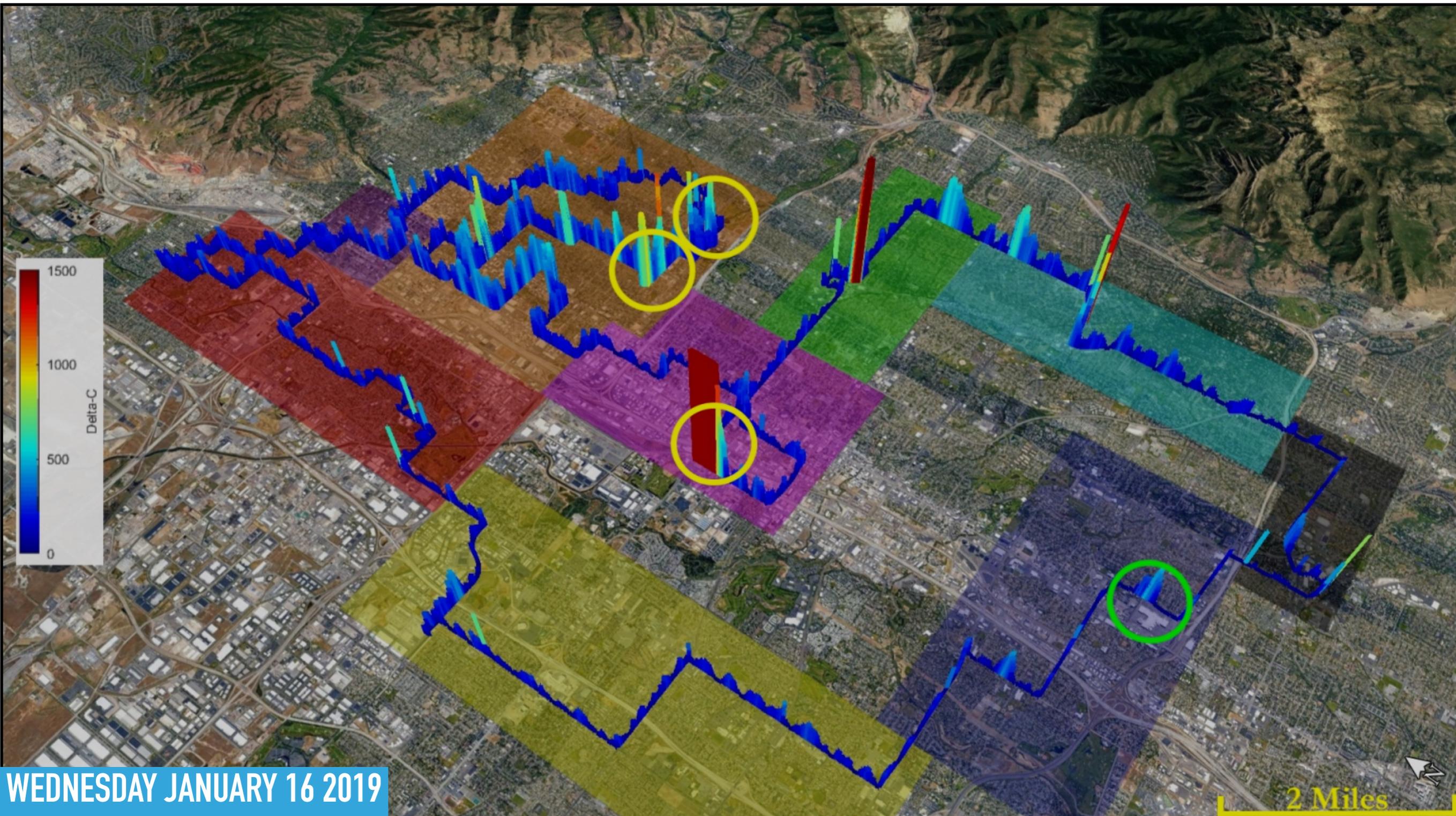
$\beta$  is baseline value

$\sigma$  is centered moving standard deviation

# PM2.5, UNRESTRICTED ACTION

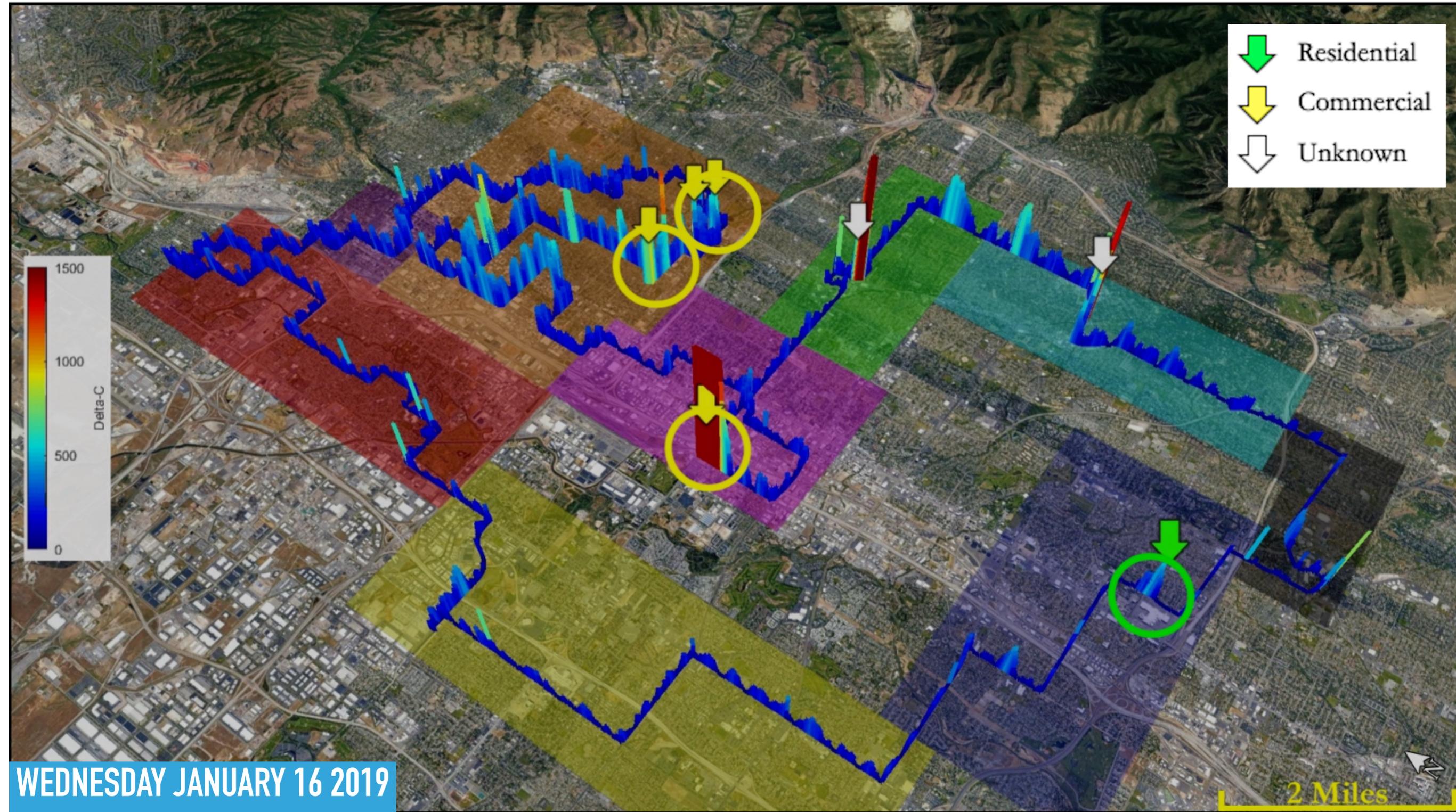


# DELTA-C, UNRESTRICTED ACTION

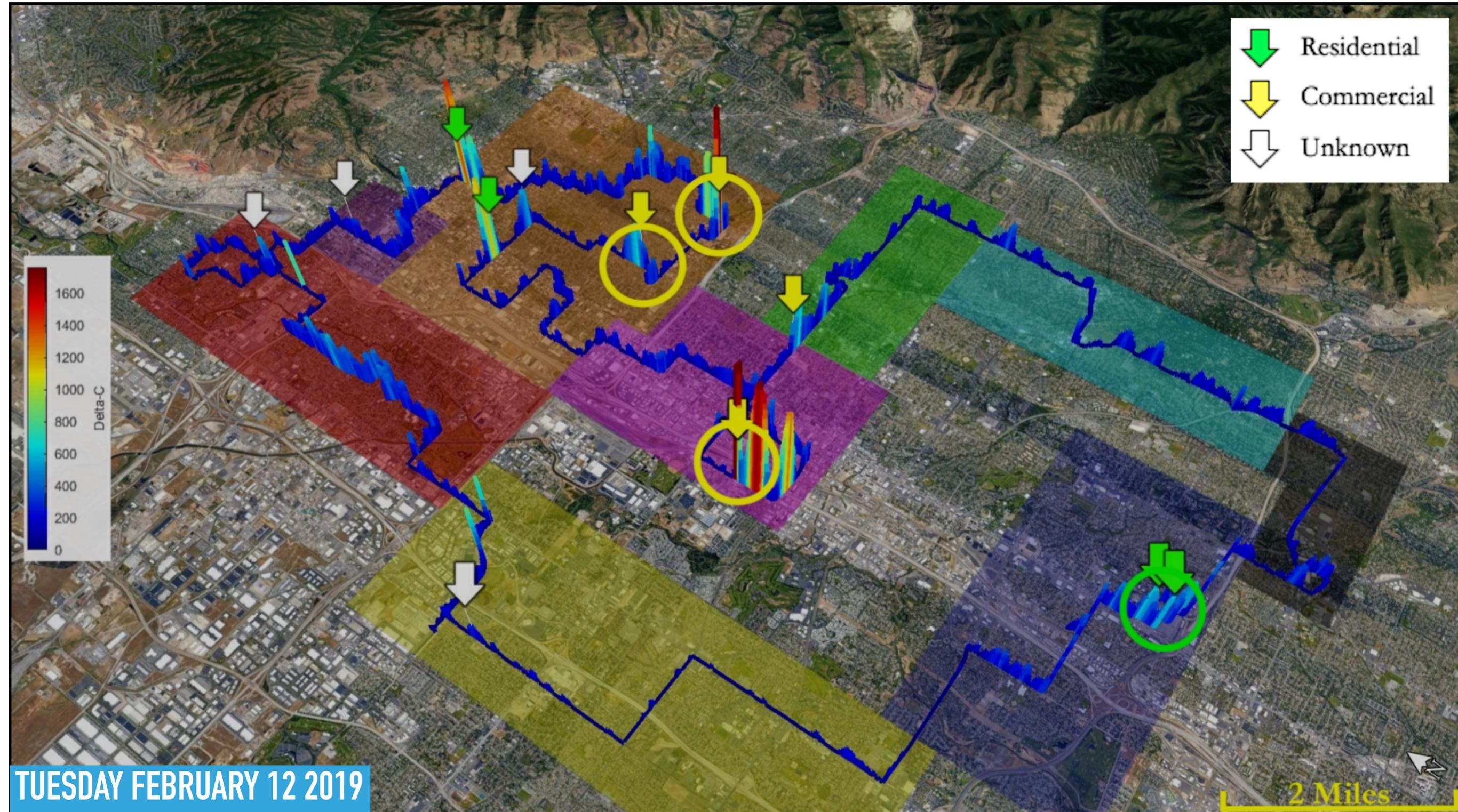


WEDNESDAY JANUARY 16 2019

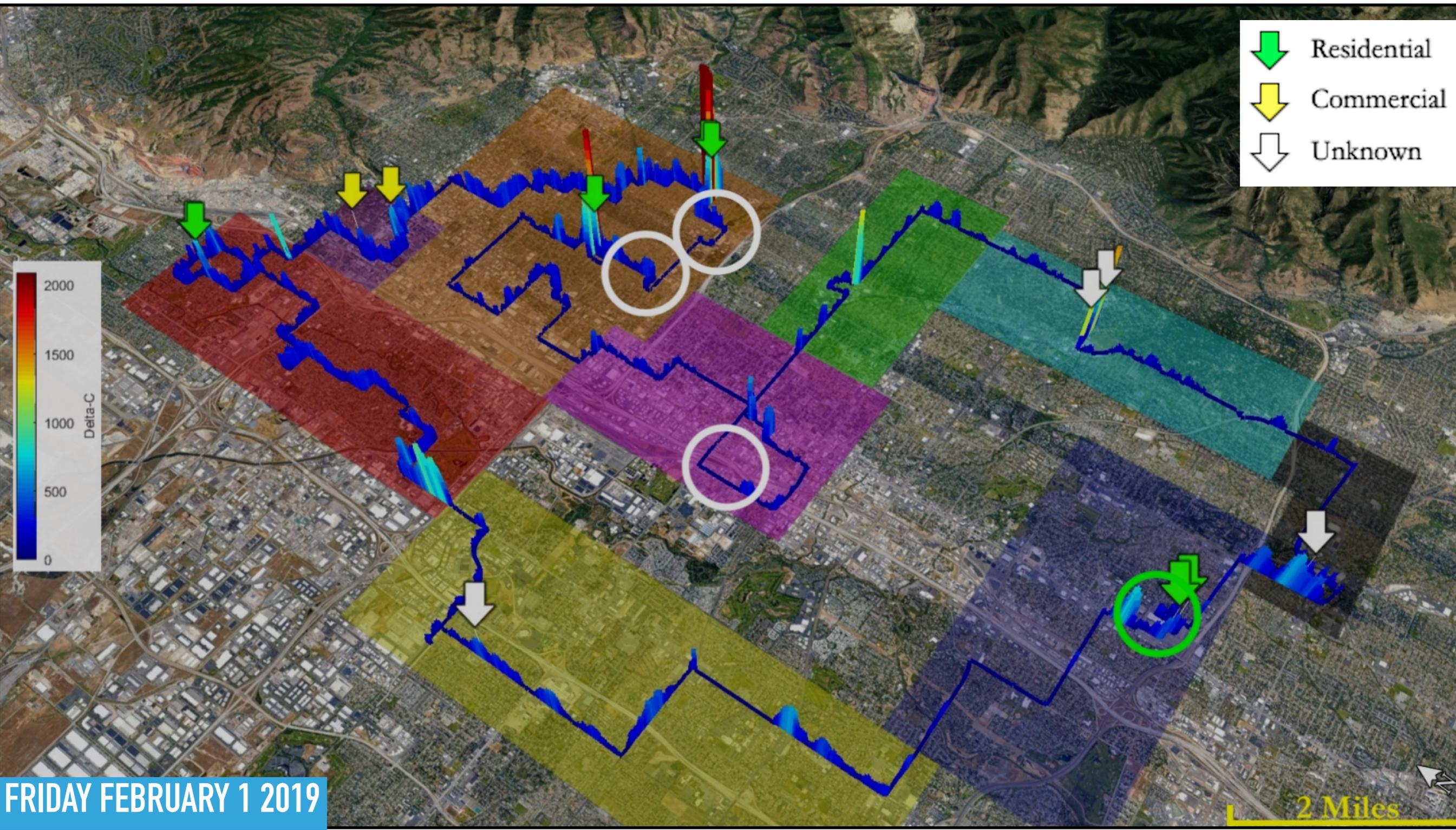
# DELTA-C, UNRESTRICTED ACTION



# DELTA-C, VOLUNTARY ACTION



# DELTA-C, MANDATORY ACTION



# FINDINGS

- ▶ Most wood-burning events occur during evening hours
- ▶ Residential wood-burning activity despite restrictions on residential wood-burning
- ▶ Commercial wood-burning contributes to winter-time PM2.5

# WHAT'S NEXT?

- ▶ Estimate compliance rate
- ▶ Determine effectiveness of wood-burning restrictions

# ACKNOWLEDGEMENTS

- ▶ Utah State Legislature
- ▶ Air Monitoring Section, Utah Division of Air Quality
- ▶ Research assistants and students, University of Utah

**THANK YOU**

# BASELINE ESTIMATION

$z$  = Centered moving mean

$i$  = Index

$\alpha$  = Window (300 s)

$t$  = Time,  $\{t \in \mathbb{Z} \mid 1 \leq t \leq n\}$

$n$  = Number of elements in data set

$x$  = Value (PM<sub>2.5</sub> or Delta-C)

$$z_t = \begin{cases} \left(\frac{1}{\alpha+t}\right) \sum_{i=1}^{\alpha+t} x_i, & t \leq \alpha & \text{(First 300 Data Points)} \\ \left(\frac{1}{\alpha+(n-t)+1}\right) \sum_{i=t-\alpha}^n x_i, & t \geq n - \alpha & \text{(Last 300 Data Points)} \\ \left(\frac{1}{2\alpha+1}\right) \sum_{i=t-\alpha}^{t+\alpha} x_i, & t = \alpha + 1, \alpha + 2, \dots, n - \alpha & \text{(Central Data Points)} \end{cases}$$

For example, let  $\alpha = 300$  and  $n = 1000$ :

$$z_t = \begin{cases} \text{if } t = 10, & \left(\frac{1}{310}\right) \sum_{i=1}^{310} x_i = \frac{(x_1 + x_2 + \dots + x_{310})}{310} \\ \text{if } t = 991, & \left(\frac{1}{310}\right) \sum_{i=691}^{1000} x_i = \frac{(x_{691} + x_{692} + \dots + x_{1000})}{310} \\ \text{if } t = 500, & \left(\frac{1}{601}\right) \sum_{i=200}^{800} x_i = \frac{(x_{200} + x_{201} + \dots + x_{800})}{601} \end{cases}$$

# BASELINE ESTIMATION

$\sigma$  = Centered moving standard deviation

$y$  = Adjusted value

$i$  = Index

$\alpha$  = Window (300 s)

$t$  = Time,  $\{t \in \mathbb{Z} \mid 1 \leq t \leq n\}$

$n$  = Number of elements in data set

$$\sigma_t = \begin{cases} \sqrt{\frac{\sum_{i=1}^{\alpha+t} (x_i + z_t)^2}{\alpha + t - 1}}, & t \leq \alpha & \text{(First 300 Data Points)} \\ \sqrt{\frac{\sum_{i=t-\alpha}^n (x_i + z_t)^2}{\alpha + (n - t)}}, & t \geq n - \alpha & \text{(Last 300 Data Points)} \\ \sqrt{\frac{\sum_{i=t-\alpha}^{t+\alpha} (x_i + z_t)^2}{2\alpha}}, & t = \alpha + 1, \alpha + 2, \dots, n - \alpha & \text{(Central Data Points)} \end{cases}$$

$$y_t = \begin{cases} z_t, & \text{if } |x_t - z_t| \geq \sigma_t \\ x_t, & \text{if } |x_t - z_t| < \sigma_t \end{cases}$$

$\beta$  = Baseline value

$y$  = Adjusted value

$i$  = Index

$\alpha$  = Window (300 s)

$t$  = Time,  $\{t \in \mathbb{Z} \mid 1 \leq t \leq n\}$

$n$  = Number of elements in data set

$$\beta_t = \begin{cases} \left( \frac{1}{\alpha + t} \right) \sum_{i=1}^{\alpha+t} y_i, & t \leq \alpha & \text{(First 300 Data Points)} \\ \left( \frac{1}{\alpha + (n-t) + 1} \right) \sum_{i=t-\alpha}^n y_i, & t \geq n - \alpha & \text{(Last 300 Data Points)} \\ \left( \frac{1}{2\alpha + 1} \right) \sum_{i=t-\alpha}^{t+\alpha} y_i, & t = \alpha + 1, \alpha + 2, \dots, n - \alpha & \text{(Central Data Points)} \end{cases}$$

# WOOD-BURNING EVENT IDENTIFICATION

$x^{PM}$  = PM<sub>2.5</sub> values

$\beta^{PM}$  = PM<sub>2.5</sub> baseline values

$\sigma^{PM}$  = PM<sub>2.5</sub> standard deviation values

$x^{DC}$  = Delta-C values

$\beta^{DC}$  = Delta-C baseline values

$\sigma^{DC}$  = Delta-C standard deviation values

$t$  = Time,  $\{t \in \mathbb{Z} \mid 1 \leq t \leq n\}$

$\delta$  = Buffer period,  $\{\delta \in \mathbb{Z} \mid -10 \leq \delta \leq 10\}$

$$\left\{ \begin{array}{ll} \text{Event,} & \text{if } |x_{t+\delta}^{PM} - \beta_{t+\delta}^{PM}| \geq (2.5 * \sigma_{t+\delta}^{PM}) \\ & \text{and } |x_{t+\delta}^{DC} - \beta_{t+\delta}^{DC}| \geq (2.5 * \sigma_{t+\delta}^{DC}) \\ \text{No Event,} & \text{otherwise} \end{array} \right.$$